620
I29Eb
no.444

Illinois U. Library

Factors Affecting Baseboard Rating Test Results

by

Warren S. Harris

UNIVERSITY OF ILLINOIS BULLETIN

A REPORT OF AN INVESTIGATION

Conducted by

THE ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS

In Cooperation with

THE INSTITUTE OF BOILER AND RADIATORS MANUFACTURERS

Price: Fifty cents

UNIVERSITY OF ILLINOIS BULLETIN

Volume 54, Number 78; July, 1957. Published seven times each month by the University of Illinois. Entered as second-class matter December 11, 1912, at the post office at Urbana, Illinois, under the Act of August 24, 1912. Office of Publication, 207 Administration Building, Urbana, Ill.

Factors Affecting Baseboard Rating Test Results

by

Warren S. Harris

PROFESSOR OF MECHANICAL ENGINEERING

ENGINEERING EXPERIMENT STATION BULLETIN NO. 444

© 1957 BY THE BOARD OF TRUSTEES OF THE
UNIVERSITY OF ILLINOIS

2550—4-57—62517

UNIVERSITY
OF ILLINOIS
PRESS

CONTENTS

I. INTRODUCTION	5
1. History	5
2. Acknowledgments	5
II. EQUIPMENT	6
3. Test Rooms	6
4. Heating Units	9
III. PROBLEMS INVOLVED IN BOTH STEAM AND WATER TESTING	11
5. Problems	11
6. Room-Air Temperature	11
7. Wall Construction	12
8. Cold Room Temperatures — Cold Room Tests	13
9. Air Temperature Correction Factors	14
10. Length of Unit	15
11. Type of Test Room	15
12. Plaster Surface Temperature	16
IV. WATER TESTS	18
13. Problems	18
14. Method of Testing	18
15. Relationship Between the Average Water Temperature and the Output of the Baseboard Unit	19
16. Effect of Water Flow Rate on Output	19

FIGURES

1. General Arrangement of Cold Room and Auxiliary Equipment — Plan 6
2. General Arrangement of Cold Room and Auxiliary Equipment — Elevation 7
3. Warm Wall Test Booth 8
4. Schematic Arrangement of Test Equipment for Hot Water Tests 9
5. Baseboard Units Tested 10
6. Spiral Finned Unit E 11
7. Floor Surface Temperature Obtained with Baseboard Radiation 13
8. Effect of Baseboard on Wall Temperature 13
9. Relationship Between Cold Room Temperature and Output 14
10. Effect of Test Booth Temperature on Output of Baseboard 14
11. Effect of Active Length of Unit Tested on Output 16
12. Rate of Heating Plaster Wall 17
13. Effect of Water to Air Temperature Difference on Heat Output — Hot Water Tests 19
14. Relationship Between Water Heat Output of Baseboard and Water Flow Rate 20
15. Percent Deviation in Correction for Various Values of "x" Compared to "x" = 0.04 21

TABLES

1. Room-Air Temperatures — Cold Room Tests 12
2. Effect of Inside Wall Material on Output of Baseboard 12
3. Effect of Wall Insulation on the Output of Baseboard Radiation 12
4. Range in Room Temperatures Resulting in Errors of 1 to 5% in C_s Where True Value of "n" Is Other than 1.4 15
5. Results — Round Robin Steam Tests — Radiant Baseboard 16
6. Value of Exponent "x" in Equation $H = CW^x$ 18
7. Table of $C_w = \left(\frac{W}{500}\right)^{0.04}$ 20

I. INTRODUCTION

1. History

Much of the research work done in the I=B=R Research Home at the University of Illinois has been related to the performance of different types of radiators and convectors. In the course of this work the radiant baseboards were developed. These are long, low units resembling the ordinary baseboard used in homes and they are installed along the outside walls of the rooms in place of the wood baseboard. They have excellent performance characteristics[1] and have made a consistent gain in popular acceptance since they were first made available to the public. In view of the rapid increase in popularity of these units the Institute of Boiler and Radiator Manufacturers published an Installation Guide giving a detailed design procedure for baseboard heating systems. It was recognized that a reliable and uniform method of rating baseboard units was also needed to safeguard the interests of both the manufacturer and the user of this equipment. Since existing codes could not be applied to baseboard without modification, the problem of developing a suitable code for baseboard units was undertaken as a part of the program carried on at the University of Illinois under the terms of the cooperative research contract between the Engineering Experiment Station and the Institute of Boiler and Radiator Manufacturers.

It seemed advisable that the code for baseboard should follow the pattern of the convector code CS-140-47 issued by the Department of Commerce. Certain obvious modifications would be required to adapt the convector test code to radiant baseboard and in some instances experimental work would be required to determine the extent of change which should be made. Among the factors requiring experimental verification were:

1. Effect of test room type on the performance of baseboard.
2. Effect of wall construction on the output of the baseboard.
3. Evaluation of the exponent expressing the relationship between the output of the baseboard and the difference between the temperature of the heating medium and the temperature of the air in the test room.
4. Point at which room air temperature should be measured.
5. Effect of water velocity on the output of baseboard when operating with hot water as the heating medium.

No attempt has been made in this bulletin to formulate a testing and rating code for baseboard units. The bulletin does contain the experimental evidence on which certain provisions of a baseboard testing and rating code issued by the Institute of Boiler and Radiator Manufacturers were based.

2. Acknowledgments

The information contained in this bulletin resulted from a cooperative investigation sponsored jointly by the Engineering Experiment Station of the University of Illinois and the Institute of Boiler and Radiator Manufacturers. The investigation has been carried on as a project of the Department of Mechanical Engineering under the administrative direction of Professor N. A. Parker, department head. Acknowledgment is hereby made to K. L. Lamm and R. L. Porter, former research assistants, for their assistance in conducting many of the laboratory tests and for their part in analyzing data collected. Acknowledgment is also made to the manufacturers who furnished materials and equipment used in the investigation.

[1] "A Study of Radiant Baseboard Heating in the I=B=R Research Home," Univ. of Ill. Eng. Exp. Sta. Bull. No. 358; and "Radiant Baseboard Heating and Effects of Reduced Thermostat Setting and Open Bedroom Windows at Night," Univ. of Ill. Eng. Exp. Sta. Bull. No. 391.

II. EQUIPMENT

3. Test Rooms

Commercial Standard CS-140-47 "Testing and Rating Convectors" permits the use of three different types of test rooms. Since some manufacturers of baseboard also manufacture convectors and may be using any one of these three types of test rooms, it obviously would be desirable to use the same three types of test rooms for testing baseboard with as little change in the construction of the rooms as possible. The three test room types are defined in Commercial Standard CS-140-47 as follows:

"Warm-Wall Booth: A warm-wall booth is a room with one side open, located in a larger room. The floor of the booth shall be at least 1 ft and not more than 4 ft above the floor of the larger room. The open side of the booth shall

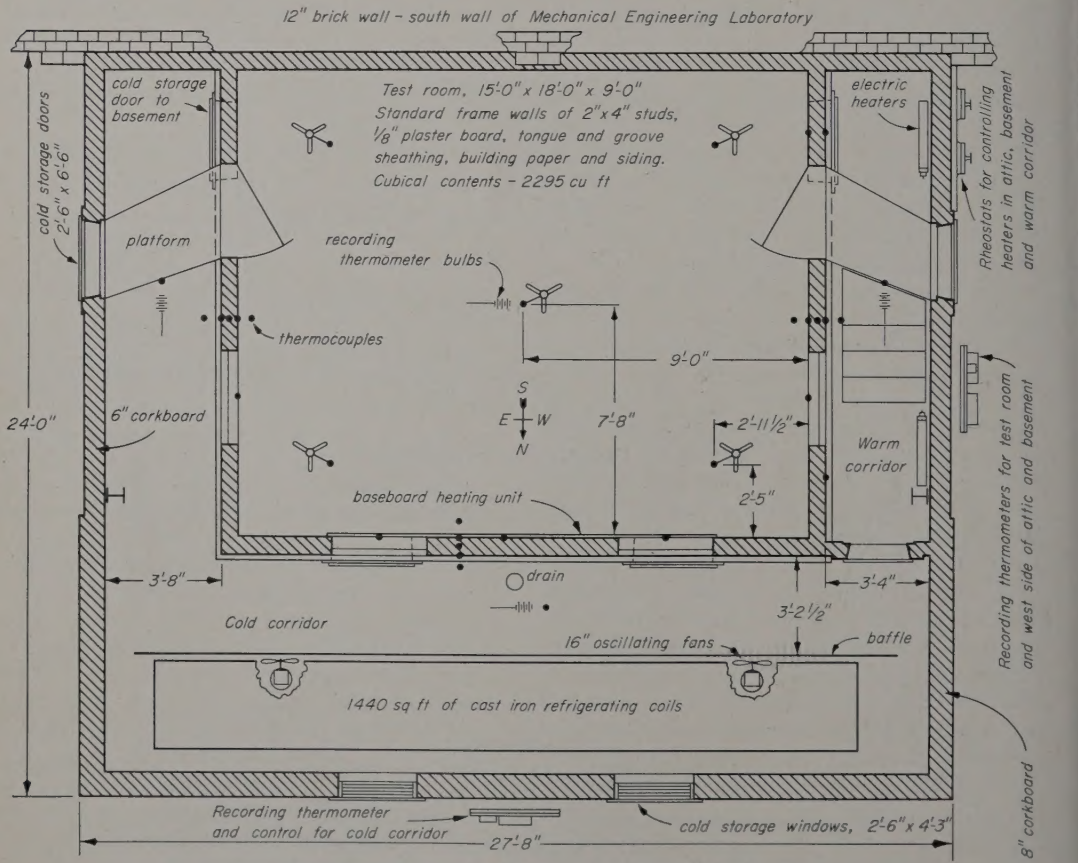

Fig. 1. General Arrangement of Cold Room and Auxiliary Equipment — Plan

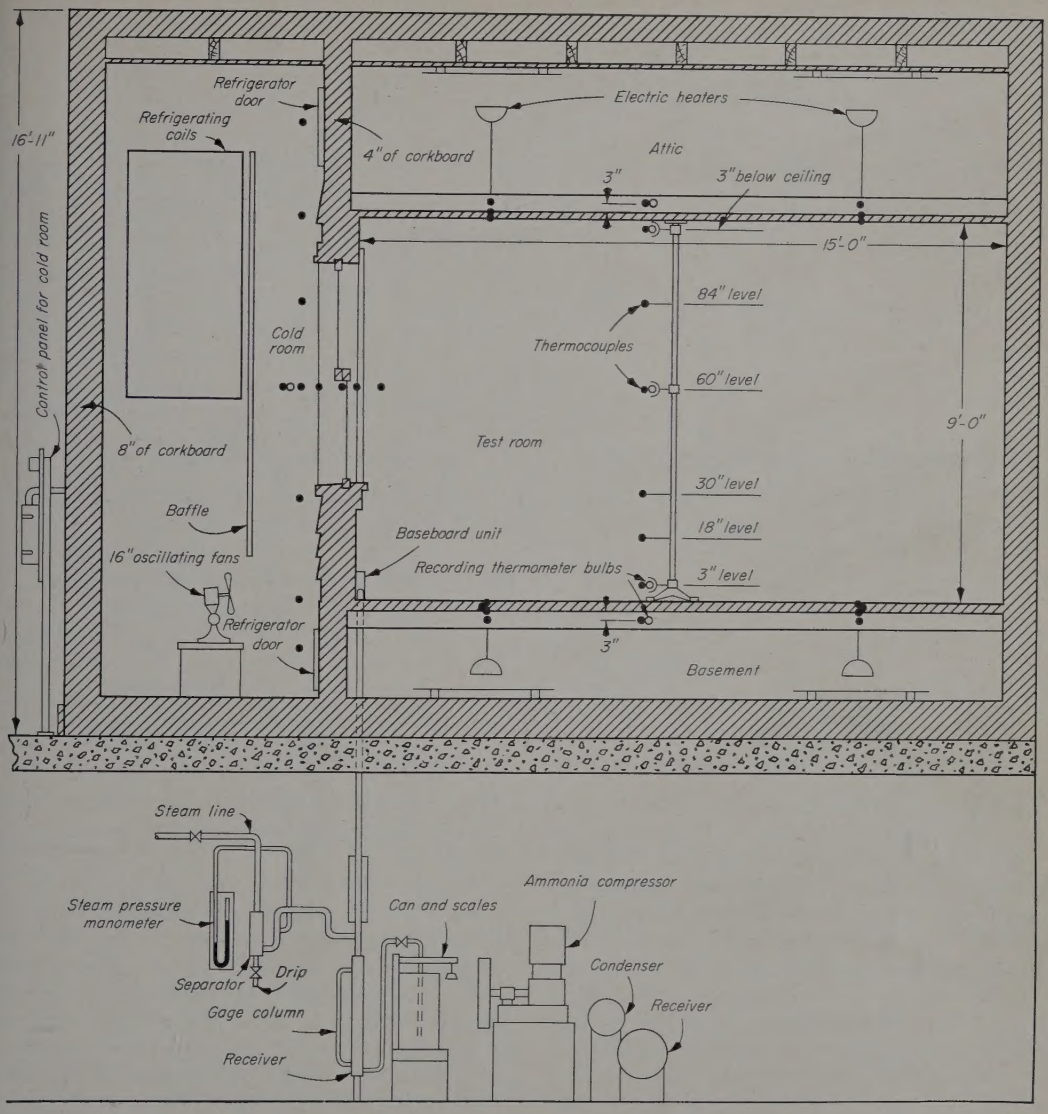

Fig. 2. General Arrangement of Cold Room and Auxiliary Equipment — Elevation

have a shield projecting down 1 ft from the ceiling. The air in the booth shall be free from draft except that created by the convector under test in the course of its normal operation.

"The test booth shall be protected from the influence of uncontrolled heat sources. The distance between any test booth wall and the wall of the surrounding room shall be not less than 2 ft and the ceiling of the test booth shall be not less than 1 ft from the ceiling of the larger room.

"Cooled-Wall Room: A cooled-wall room is a room with all sides closed, in which the inner portions of walls, ceiling, or floor are cooled by air circulating over the outer surface of the inner wall for the purpose of removing heat and maintaining suitable air temperatures in the test room. The temperature of inside surfaces

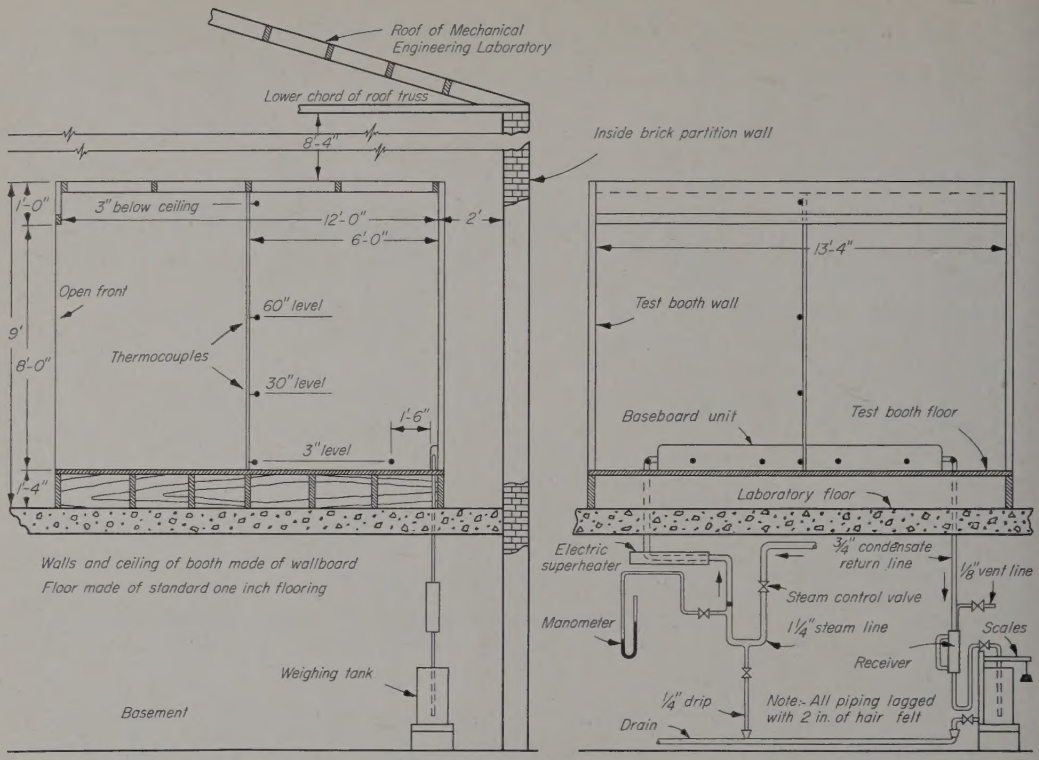

Fig. 3. Warm Wall Test Booth

shall not be lower than 55 F during the test.

"Cold Room: A cold room is a room with all sides closed which has two or more walls exposed to an air space having a temperature less than 50 F but not less than −10 F. The walls, floor, and ceiling of this test room must be of customary good building construction. The walls, ceiling, and floor exposed to the cold air shall have a heat-transmission coefficient not to exceed 0.27 Btu per sq ft per deg F difference per hour. The walls, floor, and ceiling of such a room not exposed to the cold air shall have a total heat exchange not to exceed 5% of the convector capacity. At least one of the exposed walls shall have a window of commercial construction and at least 10 sq ft in area with the top of the window stool located approximately 30 in. above the floor. The total exposed window and door area shall not exceed 25% of the exposed area, including wall, window and door."

The test facilities at the University of Illinois consisted of a cold room and two warm-wall test booths; one warm-wall booth was set up for testing with steam and the other for testing with hot water. The general arrangement of the cold room, its construction details, auxiliary and test equipment are shown in Figs. 1 and 2.

The test room was arranged so that either two or three sides could be exposed to the cold room temperature. For the tests reported in this bulletin the room was operated with two exposed walls. The temperatures of the attic, the basement and the space along the third wall of the test room were adjusted by the use of electric heaters so that there was virtually no heat flow between these spaces and the test room. The fourth wall of the test room was common with one of the insulated walls enclosing the refrigerated space.

The exposed walls of the test room were standard frame construction, consisting of bevel siding, building paper, ¾ in. tongue and groove yellow pine sheathing, 2-in. x 4-in. yellow pine studding, and ½-in. plasterboard. The ceiling was made of ⅜-in. wood lath and ⅜-in. gypsum plaster, with no flooring in the attic. The floor was of standard 2¼-in. x 13/16-in. yellow pine flooring laid over

building paper placed on ¾-in. thick tongue and groove yellow pine subfloor.

For some of the tests rock lath and gypsum plaster panels were substituted for the plasterboard on the bottom 48 in. of the exposed wall along which the test units were placed. Provision was made to add insulation of various thicknesses in this section of the wall.

The cold room was equipped with a complete thermocouple system for the purpose of observing both air and surface temperatures. The thermocouples were made of No. 22B and S gage, double cotton-covered copper and constantan wire. The leads from all the couples were formed into cables and connected to the switchboard, which was located on the lower floor of the laboratory directly underneath the cold room. Figure 2 shows the standard supporting thermocouples used in determining air temperatures at six different elevations in the center of the test room.

The warm-wall test booths at the University of Illinois were constructed in accordance with the specifications of Commercial Standard CS-140-47 except that the floor of booth No. 2 was located 8 ft above the laboratory floor. In both booths the wall against which the test units were placed was finished on the booth side with gypsum lath and plaster. Preliminary tests in both test booths indicated that the distance between the floor of booth No. 2 and the laboratory floor did not affect test results.

A section of test booth No. 1 and a detail of the piping used for steam tests is shown in Fig. 3. Figure 4 illustrates the arrangement of test equipment used in connection with booth No. 2, which was used for all hot-water tests. Booth No. 2 was built of ½-in. wall board supported by a steel frame so that the booth was not in contact with the floor, ceiling, or walls of the laboratory and was completely surrounded by the laboratory air.

By opening valves K and M, shown in Fig. 4, and by closing valve L, the test plant could be operated on gravity head furnished by water maintained at a constant level in the elevated constant-head tank E. By opening valve L, and closing valves K and M, the water from the pump B could be admitted directly into the line and circulated through the radiator or convector. Constant-head tank E was well insulated and provided with an overflow pipe to maintain a constant water level.

As the water flowed from the pump B to the constant-head tank E it passed through a steam-

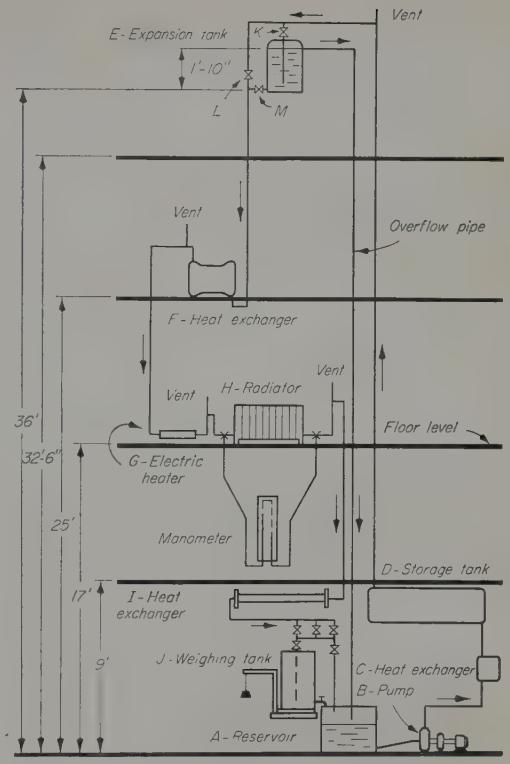

Fig. 4. Schematic Arrangement of Test Equipment for Hot Water Tests

heat exchanger C, equipped with thermostatic control, and through a well-insulated storage or control tank D. A secondary heat exchanger F, and a thermostatically-controlled electric heater G, installed just before the radiator or convector, provided the final stages of control, and permitted the water to be heated as high as 240 F.

The pump and the overflow pipe had sufficient capacities so that the storage tank remained full under all possible rates of operation of the system.

4. Heating Units

The heating units selected for study were representative of the different types of baseboard heaters on the market. Figure 5 is a photograph of the different units tested.

Unit A was a cast-iron baseboard measuring 9¾ in. high by 1¾ in. deep. An air opening 1 5/16 in. high extended the full length of the unit at the bottom and openings at the top consisted of rectangular slots ⅞ in. high by 4¼ in. long separated

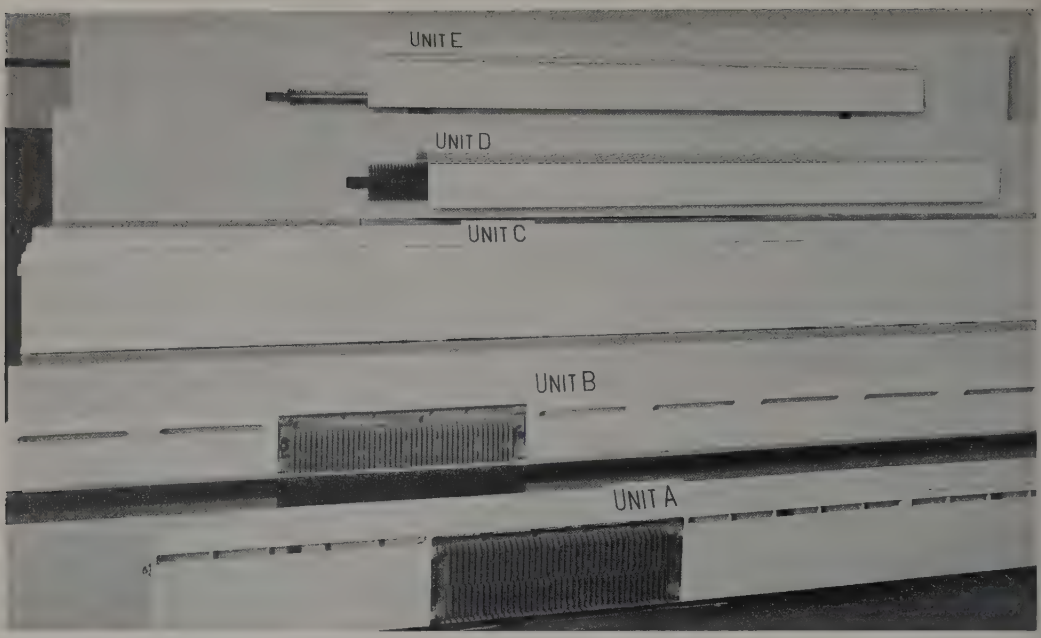

Fig. 5. Baseboard Units Tested

by ¼ in. cast-iron webs. These air openings at the top and bottom of the unit permitted room air to circulate over the finned back side of the unit. The unit was composed of 2 ft sections fastened together by push nipples at the top and the bottom. The sections were hollow so that the heating medium filled the entire casting. Unit A was used in lengths of 6 ft and 8 ft to determine end effects. This type of unit is commonly referred to as a type R C baseboard.

Unit B was another cast-iron baseboard similar to Unit A but measuring 7 in. high by 2 in. deep. An air opening 1 in. high extended the full length of the unit at the bottom and openings ¾ in. high by 9½ in. long were spaced 12 in. on centers along the top of the unit. The unit was composed of 2 ft sections fastened together by push nipples at the top and the bottom. Both the 2 ft and 1 ft end sections were available so that the length of the unit could be changed by 1 ft increments. The sections were hollow so that the heating medium filled the entire casting.

Unit C was also made of cast iron. This unit did not have the air openings at the top and bottom so that only the front face was effective as heating surface. The principal dimensions of this unit were height, 6¾ in. and depth, 1¾ in. This unit also consisted of hollow, 2 ft sections fastened together by push nipples at the top and bottom of the sections. Units of this type are designated as type R.

Unit D was a finned tube unit consisting of a 1-in. steel pipe with 2-in. x 4¼-in. steel fins spaced ⅜ in. apart. This heating element was enclosed by a sheet metal cover leaving an inlet air opening along the bottom 1⅞ in. high. The top of the sheet metal cover sloped back to the wall and was provided with a grille which served as the outlet air opening. The over-all height of the unit was 8 in. and the length 95⅜ in. The finned length of the unit was 90⅜ in.

Unit E was a finned tube unit made of a ¾-in. copper tube wrapped with a helical, finger fin having a pitch of five fins per inch. The diameter across the fins was 2¼ in. The heating element was enclosed by a sheet metal cover. At the top and bottom of the cover were slots 1¼ in. in height which served as the inlet and outlet air openings. The unit tested measured 8 ft long by 8½ in. high by 2⅜ in. deep. The finned length of the heating element was 93 in. (Fig. 6.)

III. PROBLEMS INVOLVED IN BOTH STEAM AND WATER TESTING

5. Problems

Accepting the premise that the baseboard test procedure should parallel the testing procedure for convectors as given in Commercial Standard CS-140-47, the following problems remained to be solved:

1. Location in room at which to measure room air temperature.
2. Effects of the inside finish of the wall against which the baseboard units were tested.
3. Effects on output caused by wall insulation behind the unit.
4. Effects of the cold room temperature on the performance of the baseboard units.
5. The relationship between the output of the baseboard and the steam-room air temperature difference. (Correction factor)
6. The effect of the length on the unit on output. (End effect)
7. Comparative performance in different types of test rooms.
8. Time required to establish equilibrium conditions.
9. Pitch required for proper drainage of condensate.

6. Room Air Temperature

Commercial Standard CS-140-47 contains the following statement: "This (inlet air) temperature shall be measured at three or more points spaced not more than 8 in. apart throughout the length of the inlet air opening midway between the top and bottom and 18 in. in front of the inlet."

Since some baseboard units do not have an inlet air opening it is obvious that the location at which the room air temperature is taken cannot be related to the inlet opening. Previous work done on radiators and convectors showed that good agreement between the outputs as determined in either warm wall test booth or cold room was obtained if the air temperature was measured at a point 3 in. above the floor level.

Table 1 shows the observed air temperatures for four typical cold room tests representing all four types of baseboard. These temperatures were taken 3 in. above the floor and 18 in. in front of the unit. The temperature stations were 24 in. apart with the end stations approximately 18 in. from the ends of the unit. The maximum variation in measured temperature was only 2.0 F for any test. This variation was typical of that observed in all other tests made. Thus, it seems evident that for the comparatively long baseboard units ordinarily tested, a spacing of as much as 24 in. between room air temperature thermometers is satisfactory.

There was a possibility that baseboard would tend to heat the floor more than convectors which are enclosed in a cabinet. Therefore, while it would be possible to shield the air temperature thermometers from direct radiation from the baseboard, warm convection currents from the floor might have an effect on air temperature readings taken as close as 18 in. to the unit. Figure 7 shows the floor surface temperature at various distances from

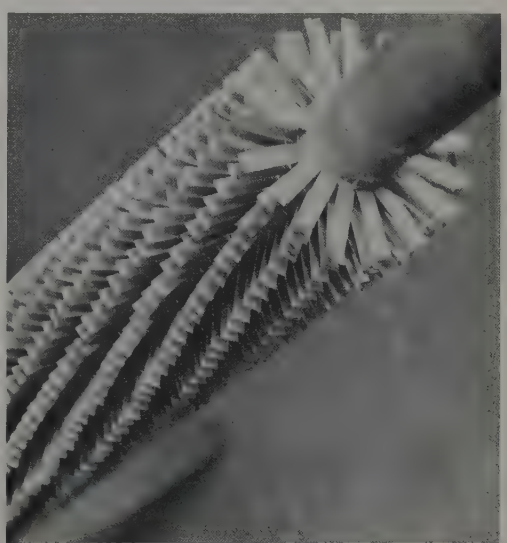

Fig. 6. Spiral Finned Unit E

Table 1

Room-Air Temperatures
Cold Room Tests

(1)	Test No.	RB-32	RB-44	RB-46	RB-14
(2)	Date	4–23–48	5–26–48	6–10–48	9–19–47
(3)	Unit	B	C	D	E
(4)	Steam Temperature in Unit, F	214.4	214.6	214.7	214.8
(5)	"Outdoor" Air Temperature, F	−0.6	−0.8	−1.0	−0.6
(6)	Test Room Air Temperature, F at center of room 3″ above floor	65.0	64.7	65.0	64.9
	Test Room Air Temperature, F 18″ in front of unit, 3″ above floor and				
(7)	18″ from right end of unit	66.2	65.5	66.0	66.0
(8)	42″ from right end of unit	66.2	65.5	65.6	65.3
(9)	center of unit	66.5	66.5	66.8	66.4
(10)	42″ from left end of unit	64.6	67.5	66.4	65.0
(11)	18″ from left end of unit	64.9	67.3	66.8	65.4

the front of a type RC radiant baseboard when operating at an average water temperature of about 210 F in a warm wall test booth. This curve is representative of conditions obtained with all types of baseboard tested. At a distance of 18 in. from the face of the unit the curve is almost horizontal showing that the floor is heated only slightly at this point. This indicates a distance of 18 in. in front of the unit is sufficient to eliminate errors in air temperature measurement resulting from an increase in floor surface temperature produced by the baseboard.

7. Wall Construction

Since baseboard units are attached to the wall, the thermal conductivity of the materials used in the construction of the wall have a direct bearing on the total output of the unit. High thermal conductivity through the wall behind the unit would permit an excessive amount of heat to pass from the back side of the baseboard directly through the wall to the outdoors. Under test conditions, this heat would appear as part of the measured capacity, but in an actual installation the heat would not be available to help offset the normal heat loss of the room. The inside wall material also may act somewhat as extended heating surface and thereby increase the useful heat output of the unit. The construction of the wall of the test booth or room against which the test units are to be located, therefore, must be standardized for valid results.

Table 2

Effect of Inside Wall Material on Output of Baseboard

Unit	Total Output in Btuh ($t_s - t_a = 150$ F)		Percent Reduction When Testing on Fiber Board Wall
	Fiber Board	Plaster	
B	3,780	3,920	3.6
D	3,540	3,740	5.4

Both walls insulated.

The cast-iron unit (unit B) and the steel finned tube unit (Unit D) were tested in the warm wall test booth against both an insulated fiber board wall and an insulated plaster wall. The results of these tests are given in Table 2. It will be noticed that the outputs were from 3.6 to 5.4% lower when testing on a fiber board wall than when testing on a plaster wall. Since both walls were insulated with 3⅝ in. of mineral wool, this difference could hardly be attributed to a change in the heat loss through the wall, but rather it must have been due to a difference in the transfer of heat to the wall and thus to the room air. Due to its high thermal conductivity, the plaster wall acted to some degree as extended heating surface for the baseboard heating unit being tested. Therefore, if comparative test results are to be obtained, it will be necessary to test all units on the same type of wall surface.

Tests to determine the effect of wall insulation on the performance of baseboard radiation were run in the cold room as the temperature differences across the wall in this test room were approximately the same as those experienced in an actual house in severe winter weather. In these tests the units were mounted against a standard frame wall with an inside surface made of gypsum plaster. In one series of tests the wall was uninsulated and in the other the stud spaces were filled with mineral wool to a height of 4 ft above the floor. The condensate outputs of the four types of baseboard radiation when operating under these two conditions are

Table 3

Effect of Wall Insulation on the Output of Baseboard Radiation

Unit	Cold Room Outputs Btuh per lin ft		Percent Decrease in Output Due to Insulating Plaster Wall
	Uninsulated Plaster Wall	Insulated Plaster Wall	
B	456	438	3.9
C	374	341	9.0
D	500	481	3.8
E	572	571	0.2

given in Table 3. From this table it will be noted that the addition of insulation to the wall decreased the condensate output of the units from 0.2% to 9.0%. The insulation had the greatest effect on the output of the type R unit (unit C) which was to be expected as there was no air circulation on the wall side of this unit. Therefore the wall was heated to a higher temperature than with the other units where air circulation on the wall side of the unit had a cooling effect on the wall itself.

The difference between the wall surface temperature and the air temperature at a distance of 1½ in. from the wall and at different heights above

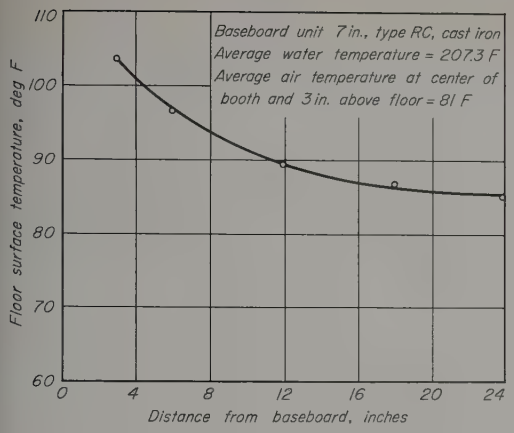
Baseboard unit 7 in., type RC, cast iron
Average water temperature = 207.3 F
Average air temperature at center of booth and 3 in. above floor = 81 F
Floor surface temperature, deg F
Distance from baseboard, inches

Fig. 7. Floor Surface Temperature Obtained with Baseboard Radiation

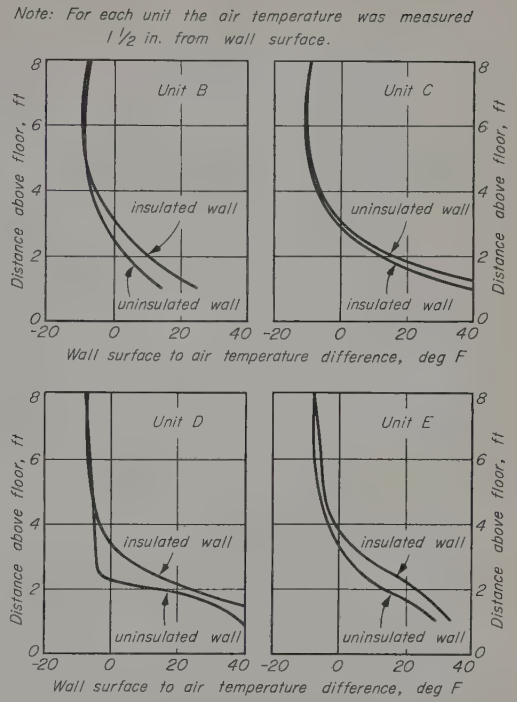
Note: For each unit the air temperature was measured 1 1/2 in. from wall surface.
Unit B
Unit C
Unit D
Unit E
insulated wall
uninsulated wall
Distance above floor, ft
Wall surface to air temperature difference, deg F

Fig. 8. Effect of Baseboard on Wall Temperature

the floor is shown in Fig. 8. In every case the wall was warmer than the air from the floor to a distance of about 3 ft above the floor, indicating that this portion of the wall was acting as extended heating surface, thus assisting the output of the baseboard. Above the 3-ft level the wall was cooler than the air indicating that above this level heat was being transferred from the room air to the wall.

With the single exception of unit C, it was found that the difference between the surface temperature of the lower 3 ft of the wall and the temperature of the air was somewhat higher in the case of the insulated wall than in the case of the uninsulated wall. This was to be expected as the wall insulation materially reduced the cooling effect of the cold stud spaces on the plaster.

8. Cold Room Temperatures — Cold Room Tests

The effect of the actual air temperature in the refrigerated space adjoining the test room on the tested output of the baseboard units was determined by testing units B and C with a fixed test room temperature of 65 F at 3 in. above the floor and with various cold room temperatures. Maintaining a constant test room temperature even though the cold room temperature was changed from test to test was accomplished by the use of an auxiliary baseboard unit of the same make as the one under test. The auxiliary unit was used in those tests in which the cold room temperature was approximately 0 F, and it was placed along the wall adjacent to the unit under test. The steam supply and the condensate piping for the auxiliary unit were separate from the piping for the test unit so that the steam consumption of the auxiliary unit was not included in the computation of the output of the test unit.

Figure 9 shows the results of the tests with different cold room temperatures. In two instances the tests were made with no insulation in the wall. In each case it was observed that as the cold room temperature was increased, there was a decrease in the output of the baseboard. The rate of decrease amounted to approximately 0.7 Btu per hr per linear ft for each degree increase in the cold room.

Unit B was also tested using an insulated wall and under these conditions it was found that the cold room temperature had essentially no effect on the output of the baseboard. With the insulated wall the reduction in the output of the baseboard amounted to about 0.2 Btu per hr per linear ft for each degree rise in the cold room temperature.

Assuming 300 Btu per hr per linear ft to be the lowest baseboard output which is likely to be encountered, the curves of Fig. 9 indicate that a 21 F change in the cold room temperature would result in a 5% change in the output of the baseboard if

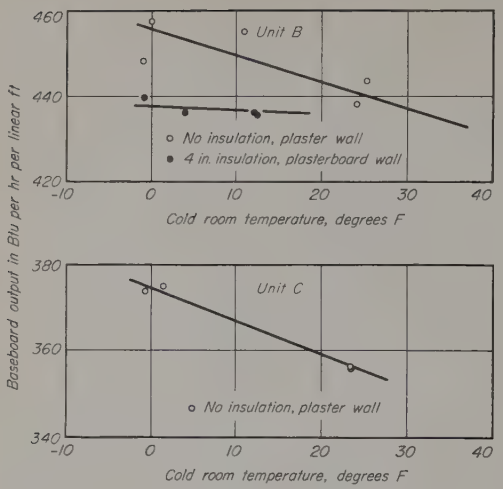
Unit B
No insulation, plaster wall
4 in. insulation, plasterboard wall
Cold room temperature, degrees F
Unit C
No insulation, plaster wall
Cold room temperature, degrees F
Baseboard output in Btu per hr per linear ft

Fig. 9. Relationship Between Cold Room Temperature and Output

tested against an uninsulated wall. On the other hand, the same baseboard tested against a wall insulated with 4 in. of mineral wool required a 75 F change in cold room temperature to effect a 5% change in the baseboard output. Hence, it is evident that if the units are tested against an insulated wall the temperature of the cold room will have no appreciable effect on the output of the tested unit. Because of this, the final adjustment of the test room temperature may be made by raising or lowering the temperature of the cold room, making the use of an auxiliary heating unit in the test room unnecessary.

9. Air Temperature Correction Factors

Since warm wall booths are open to the laboratory in which they are located, it is difficult, if not impossible, to regulate the temperature of the air in the booth within very close limits as may be done in both the cold room and the cooled wall room. Instead it is necessary to permit more latitude in the air temperature maintained and correct the test results to a standard condition.

In order to determine the correction factors to be used and the maximum permissible range of air temperature, four types of units were tested in the warm wall booth over a comparatively wide range of air temperatures. In all of these tests the saturated steam temperature in the radiator was held constant at 215 F.

The results of these tests are shown graphically

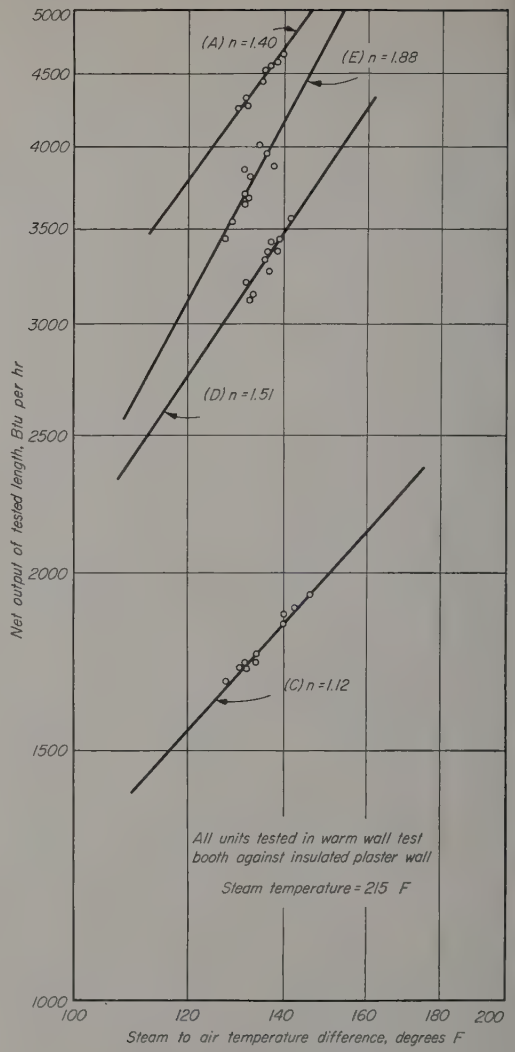
(A) n = 1.40
(E) n = 1.88
(D) n = 1.51
(C) n = 1.12
All units tested in warm wall test booth against insulated plaster wall
Steam temperature = 215 F
Net output of tested length, Btu per hr
Steam to air temperature difference, degrees F

Fig. 10. Effect of Test Booth Temperature on Output of Baseboard

in Fig. 10 in which the outputs of the units have been plotted against the steam to air temperature difference. When plotted on log paper the test points fall on straight lines indicating that the outputs of the units may be expressed by the general equation:

$$H = a\,(t_s - t_a)^n \qquad (1)$$

where

H = Heat output of the unit at test conditions in Btu per hr

t_s = Temperature of the steam in the radiator in deg. F

t_a = Temperature of the air in the test room during the test 3 in. above the floor in deg. F

a = A constant

n = Slope of the curve (Fig. 10)

If the slope of the curve is known, tests may be made at any room temperature and then corrected to a standard air temperature by the use of the equation:

$$H_s = C_s H \tag{2}$$

where

$$C_s = \left(\frac{t_s - t_a'}{t_s - t_a}\right)^n \tag{3}$$

and

H_s = Heat output of the unit at standard air temperature in Btu per hr

C_s = A correction factor

t_a' = The standard air temperature in deg. F

Other symbols are the same as before.

If the curves in Fig. 10 all had the same slope, values of C_s could be used for all the units with no limitation on the room air temperature during the test. Since the curves do not have exactly the same slope it is necessary to determine the values of C_s for each unit to be tested or to use average values of C_s and determine the range of room air temperatures which may be permitted without introducing too great an error in the corrected heat output rate. The latter procedure seemed the more practical.

The slopes of the curves in Fig. 10 range from 1.12 to 1.88. Accepting 1.4 as the mean slope and substituting 1.40 in Eq. 3 in place of n, values of C_s may be determined which will be correct only when the true slope of the curve for the unit under test is 1.4. If it is necessary to determine H_s to an accuracy of $\pm 5\%$, a practical commercial limitation, then the maximum deviation of t_a from t_a' for which the average value of C_s may be used may be derived from Eq. 3 in the form of:

$$\frac{t_s - t_a'}{t_s - t_a} = (1 \pm \text{allowable error})^{\frac{1}{n-1.4}} \tag{4}$$

The allowable range in test room temperature for various values of n and required accuracies as determined from Eq. 4 are given in Table 4.

Table 4

Range of Room Temperatures Resulting in Errors of 1 to 5% in C_s Where True Value of n Is Other Than 1.4

n	Allowable Error, in percent				
	1	2	3	4	5
	Range in Test Room Temperatures,* F				
0.8	62–67	60–70	57–72	55–75	52–77
1.0	61–68	57–72	53–76	50–80	46–83
1.2	57–72	49–79	41–86	32–93	24–99
1.4			No Limit		
1.6	57–72	49–79	40–86	32–92	21–98
1.8	61–69	57–73	53–76	49–79	44–82
2.0	62–68	60–70	57–72	55–76	52–77
2.2	63–67	61–68	59–70	57–72	55–74

* Table based on standard room temperature = 65 F and heating unit supplied with steam at 215 F.

10. Length of Unit

Tests to determine the effect of the length of unit tested on the output per linear ft (end effect) were made on Units A and B. The tests were made in the warm wall test booth in order that changes could be made in the length of the unit under test without affecting the temperature of the test room. Six ft and 8 ft assemblies were used with both unit A and unit B, and the results of the tests are shown in Fig. 11. No measurable difference appeared in the results obtained with the two different lengths tested. It was concluded, therefore, that the end effect on baseboard radiation is negligible, particularly if the unit tested is 7 ft or longer.

11. Type of Test Room

In order to determine if test results could be duplicated in different laboratories one of each of four types of units listed in Section 4 were selected for a round robin test program in which the four units selected were tested in seven different industrial and University laboratories. Steam was used as the heating medium. The warm wall booth, the cooled wall room and the cold room were all represented.

The tests were made by different men in each of the laboratories but the same test procedure was followed in every case. The procedure followed was the one which was later adopted as the steam test procedure in the first edition of the I=B=R Testing and Rating Code for Baseboard Type of Radiation.

A summary of the round robin tests is given in Table 5. Examination of the table shows that in tests made in a cooled-wall room, the outputs were invariably higher than those obtained when the same unit was tested in a cold room or warm-wall test room. In some instances the data supplied by the laboratories making the tests were not sufficiently complete to determine the exact conditions of the test. If cooled air was circulated through the wall behind the unit under test, or if the inside wall

surface temperatures were unusually low, the test output of a baseboard would be increased. When testing radiators or convectors however, cooled air can be circulated through all the walls of the room without seriously affecting the output of the unit. Since the cooled wall rooms used in the round robin program were originally constructed for the purpose of testing convectors, it may be that even during the round robin tests, the cooled air was circulated through all of the walls of these rooms.

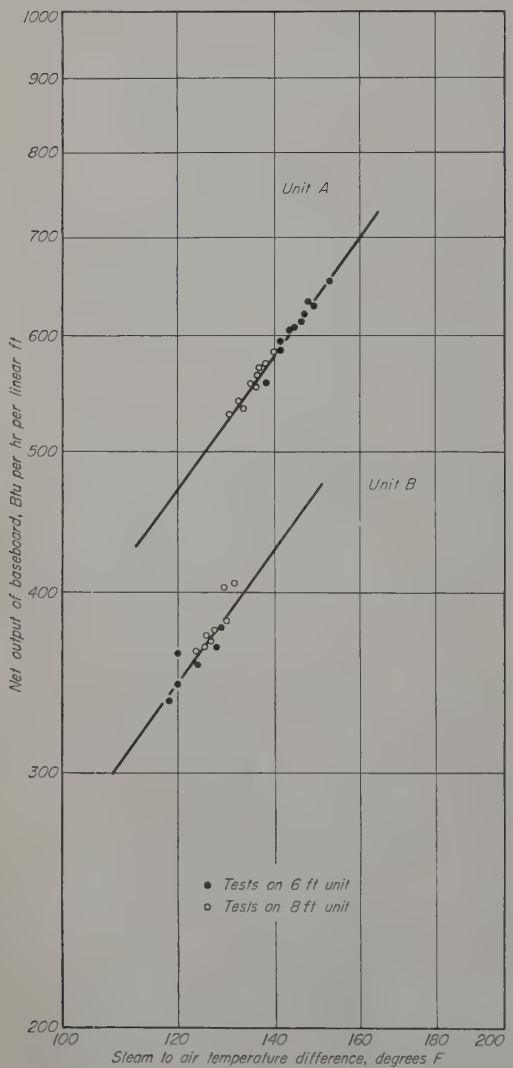

Fig. 11. Effect of Active Length of Unit Tested on Output

The test results obtained in all cold rooms and warm wall test booths agreed within 9%, and if one test of doubtful accuracy was excluded the results agreed within 5%. If data from the cooled wall rooms are included the maximum deviation from the average is about 22%, or excluding the doubtful test, about 14%.

The multiple tests indicated that approximately the same results may be expected from the cold room and the warm wall test booth, but that heat output rates obtained in a cooled wall room may be high. If the cooled wall room is used, cooled air must not be circulated below the 30-in. level in the wall along which the unit is located. Furthermore, the section of this wall from the 30-in. level to the floor should be completely insulated just as is the case in the cold room and warm wall test booth.

12. Plaster Surface Temperature

One preliminary test was made to determine the maximum plaster temperature when operating a type C unit on steam at 215 F and to determine the rate of change in the plaster temperature upon starting the unit in operation. This test was made in the warm wall test booth with the unit located along an insulated plaster wall.

Figure 12 shows that for about 5 min after steam was first turned on there was no change in the temperature of the plaster wall. During much of this time air was being expelled from the heating unit and the piping system. During the next 2½ hr there was a sharp increase in the plaster temperature, the rate of increase at the 3-in. level being especially rapid for the first hour. After 2½ hr of operation there was little or no further change in the plaster temperature at any level. Figure 12 indicates that a period of about 2½ hr is required to

Table 5

Results — Round Robin Steam Tests
Radiant Baseboard

Laboratory	Unit B	Unit C	Unit D	Unit E	Test Room
1	438	341	481	571	Cold Room
2	462			592	Cold Room
3	472	380*	505	585	Cold Room
4	470	333	488	590	Warm Wall Booth
5	453	337	469	562	Warm Wall Booth
6	469	378	516	610	Cooled Wall Room
7	535	452	508	522	Cooled Wall Room
Average All Labs.	471	370	495	576	
Maximum Percent Deviation All Labs.	13.6	22.2	5.3	9.4	
Average Cold Room and Warm Wall Booth	459	348	486	580	
Maximum Percent Deviation from Average	4.6	9.2	3.9	3.1	
Average Cold Room and Warm Wall Booth Excluding Doubtful Test	459	337	486	580	
Maximum Percent Deviation from Average	4.6	1.2	3.9	3.1	

All outputs corrected to total enclosure length.
* Accuracy of test in doubt.

reach a steady state condition when making a test from a cold start.

If output tests are run before a steady state condition is attained there is some danger that abnormally high condensate rates may be obtained. Fortunately the heat loss from the unit to the wall is small in comparison to the heat transfer between the unit and the room air, and therefore the plaster temperature does not have too great an effect on the total output of the unit. Usually it was found that the condensate rate remained constant after 1 hr of operation.

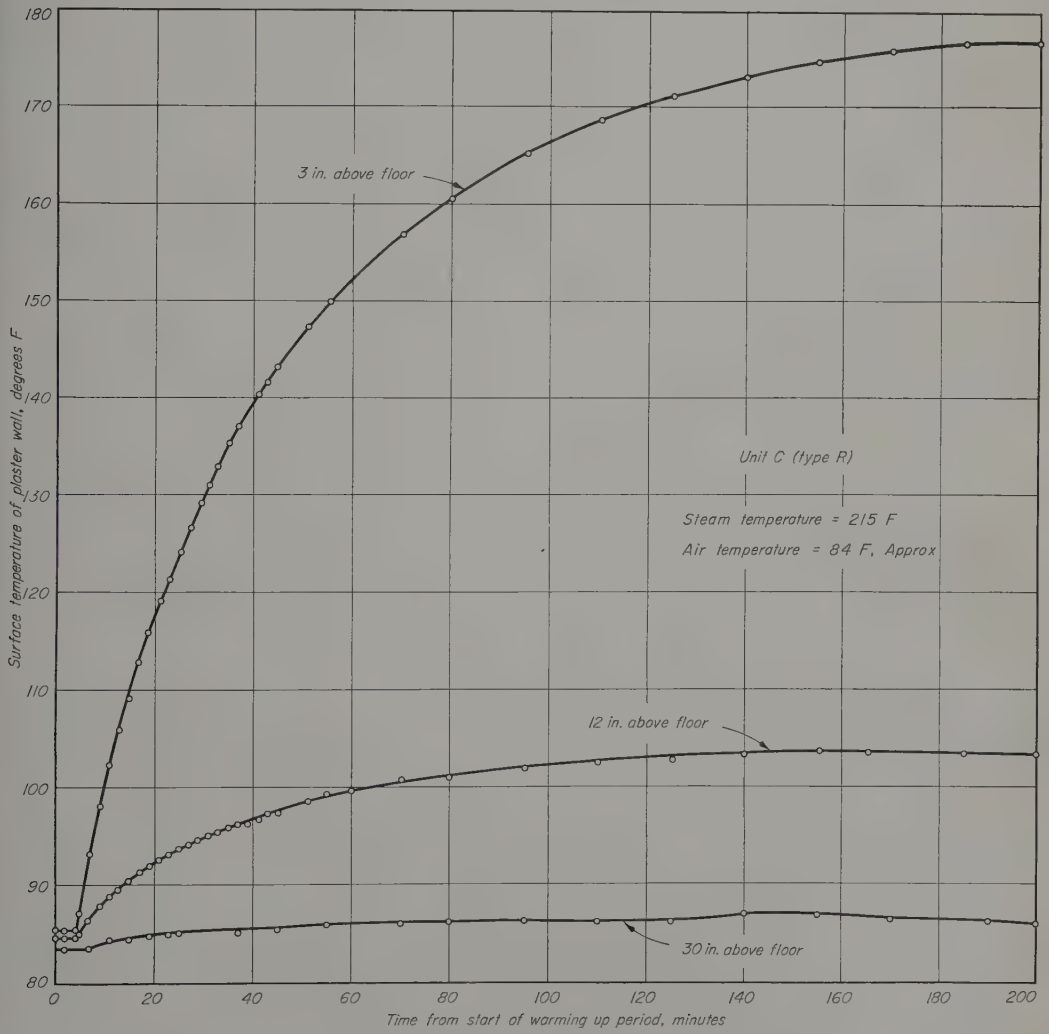

Fig. 12. Rate of Heating Plaster Wall

IV. WATER TESTS

13. Problems

The determination of the heat output of a baseboard heating unit when using hot water as the heating medium is complicated by two problems which do not present themselves when making steam tests. In performing hot water tests the effects of water velocity and water temperature on the heat output of the unit must be taken into consideration. These effects could be studied in the warm wall test booth without the necessity of repeating the tests in other types of test rooms as the effects of the test room itself were previously studied in connection with steam tests.

Several methods of testing baseboard for water heat output present themselves. Tests may be made on the basis of 1) constant water temperature drop per ft of baseboard length, or 2) constant rate of flow of water through the unit. Since the film coefficient of heat transfer is a function of rate of flow, the second method of testing was considered the preferable. This method also appeared to be the simpler from the standpoint of establishing and maintaining test conditions in the laboratory.

14. Method of Testing

The same tests were used to determine both the effect of water velocity on heat output and the relationship between the heat output of the unit and the water to room air temperature difference. These tests were made in the warm wall test booth. Tests were made at water flow rates of 125, 250, 500 and 1000 lb per hr. At each flow rate the water temperature was varied from a low of about 150 F to a high of approximately 210 F. For each water flow rate, a curve was plotted (Fig. 12) using the temperature of the water minus the temperature of the room air as the abscissa and heat output in Btuh per linear ft as the ordinate.

Table 6

Value of Exponent "x" in Equation $H = CW^x$

Unit Designation	Approx. Height	Approx. Depth	Material Core	Material Fin	Fins per Inch	No. of Tubes or Waterways	Water Temp., F	Exponent
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	7″	2″	CI	CI		1	215	0.004
							165	0.000
2	8″	2″	Steel	Steel		1—1″	215	0.010
							165	0.017
3	8½″	3⅜″	Cu	Cu		1—¾″	215	0.015
							165	0.029
4	9¾″	1¾″	CI	CI		1	215	0.020
							165	0.000
5	7″	2″	CI	CI		1	215	0.036
							165	0.028
6	10″	3¼″	Cu	Steel	4	1—1″	215	0.033
							165	0.038
7	9⅜″	1⅜″	CI	CI		1	215	0.060
							165	0.050
8	9⅜″	1⅞″	CI	....		1	215	0.060
							165	0.050
9	9⅜″	1⅜″	CI	....		1	215	0.040
							165	0.040
10	7″	2⅜″	Non-ferrous	....	5	1—¾″	215	0.040
							165	0.035
11	8″	2½″	Cu	Non-ferrous	3	2—½″	215	0.080
							165	0.060
12	8″	2¼″	Steel	Steel	2.7	1—1″	215	0.075
							165	0.075
13	9″	3″	Steel	Steel	2.7	1—1¼″	215	0.035
							165	0.030
14	7¼″	3⅜″	Non-ferrous	....	5	1—¾″	215	0.050
							165	0.040
15			Cu	AL	4.85	1—¾″	215	0.050
							165	0.060
16			Cu	....		1—¾″	215	0.055
							165	0.070
						Average	215	0.0415
							165	0.0389
							All	0.0402

15. Relationship Between the Average Water Temperature and the Output of the Baseboard Unit

The curves in Fig. 13 show the relationship between output and water to air temperature difference for all 5 units when tested at a water flow rate of 500 lb per hr. The curves are exponential in character and may be represented by the general equation:

$$H = B\,(t_w - t_a)^n \qquad (5)$$

in which

H = Heat output of the baseboard in Btuh per linear ft
B = A constant, determined by test
t_w = Average temperature of the water in the baseboard during the test
t_a = Average temperature of the air in the test booth 3 in. above the floor and 18 in. in front of the baseboard unit
n = An exponent, determined by test

Of the 5 units tested the exponent, n, varied from 1.23 to 1.42. This variation is sufficient to show that to obtain water heat outputs accurately within ±3% it will be necessary to test each unit at each water temperature for which catalog ratings are desired rather than to test at a single water temperature and compute the ratings at other water temperatures by using a correction factor based on an average value of the exponent, n.

16. Effect of Water Flow Rate on Output

In order to show the effect of the water flow rate on the heat output of the different units, curves similar to the ones shown in Fig. 13 were plotted for each water flow rate listed in Section 14. The curves in Fig. 14 were derived from these curves by replotting the heat output at a selected water to air temperature difference against the corresponding flow rate. When plotted on log-log paper the curves were straight lines indicating the relationship between the heat output and the water flow rate was of the form:

$$H = CW^x \qquad (6)$$

where

H = Heat output in Btuh per linear ft
W = Water flow rate in lb per hr
C = A constant, determined by test
x = An exponent, determined by test

In addition to the several units tested in the laboratory, curves, as shown in Fig. 14, were drawn for

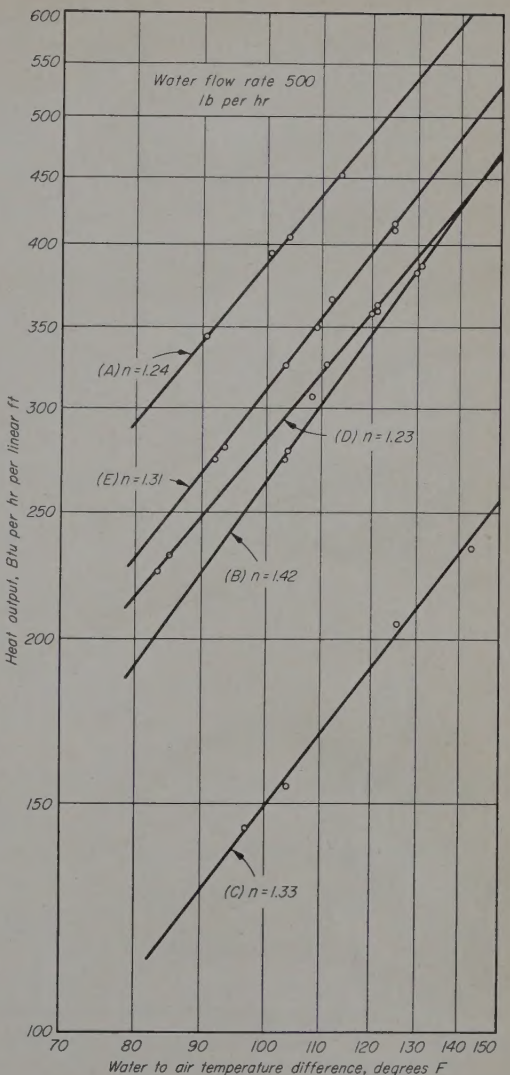

Fig. 13. Effect of Water to Air Temperature Difference on Heat Output — Hot Water Tests

different baseboard units of all styles from data submitted from various company laboratories.

The tests included both cast-iron and finned tube units. The height of the units ranged from 7 in. to 10 in. and the depth from 1¾ in. to 3¼ in. One of the finned tube units had two ½ in. tubes in parallel. All other finned tube units had only one tube. Tube diameters ranged from ¾ in. to 1¼ in.

The values of "x" as determined by the tests both at the University of Illinois and at company

laboratories are tabulated in Table 6 for water temperatures of 165 F and 215 F. The value of "x" ranged from 0.000 to 0.08, averaging 0.0415 at a water temperature of 215 F and 0.0389 at a water temperature of 165 F. The average for all tests irrespective of water temperature was 0.0402.

Examination of Table 6 shows that 41% of the tests resulted in values of "x" between 0.03 and 0.05 inclusive, 69% of the tests gave values of "x" between 0.02 and 0.06 inclusive, and 81% of the tests gave values of "x" between 0.01 and 0.07.

The following mathematical analysis serves as a check on the value of "x" as determined experimentally. The mathematical analysis is based on the following assumptions.

Type of unit = finned tube

Inside tube diameter = ¾ in.

Ratio of inside surface area of tube to total tube and fin surface exposed to air = 1 to 20

Entire fin is at the same metal temperature as the tube.

Thermal resistance of the metal = neglected.

Water film temperature = 200 F

Air film coefficient = 2.0 Btuh per sq ft (F)

The resistance to heat flow from the water within the tube to the air surrounding the baseboard unit consists of:

(1) the water film resistance $= \frac{1}{A_w f_w}$ where A_w is area of tube in contact with water, and f_w is water heat transfer coefficient.

(2) the air film resistance $= \frac{1}{A_a f_a}$

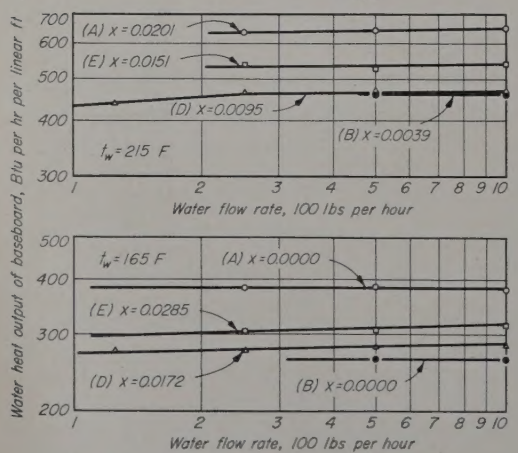

Fig. 14. Relationship Between Water Heat Output of Baseboard and Water Flow Rate

Table 7

Table of $C_w = \left(\frac{W}{500}\right)^{0.04}$

W	C_w	W	C_w	W	C_w
150	0.953	1050	1.030	1950	1.056
200	0.964	1100	1.032	2000	1.057
250	0.973	1150	1.034	2050	1.058
300	0.980	1200	1.036	2100	1.059
350	0.986	1250	1.038	2150	1.060
400	0.991	1300	1.039	2200	1.061
450	0.996	1350	1.041	2250	1.062
500	1.000	1400	1.042	2300	1.063
550	1.004	1450	1.044	2350	1.064
600	1.007	1500	1.045	2400	1.065
650	1.011	1550	1.046	2450	1.066
700	1.014	1600	1.048	2500	1.067
750	1.016	1650	1.049	2600	1.068
800	1.019	1700	1.050	2700	1.070
850	1.021	1750	1.051	2800	1.071
900	1.024	1800	1.053	2900	1.073
950	1.026	1850	1.054	3000	1.074
1000	1.028	1900	1.055		

therefore the total resistance to heat flow is

$$R = \frac{1}{A_w f_w} + \frac{1}{A_a f_a} = \frac{1}{A_w f_w} + \frac{1}{20 A_w f_a} \qquad (7)$$

The water film coefficient is a variable and is expressed by the equation:

$$f_w = 160\,(1 + 0.012 t_f)\,\frac{V_w^{0.8}}{D^{0.2}} \qquad (8)$$

in which

t_f = Water film temperature = 200 F

V_w = Water velocity in tube in ft per sec

D = Inside diameter of tube in inches = 0.75 in.

Selecting a water velocity of 1 ft per sec and substituting proper numerical values in Eq. 8 it will be found that

f_w (at $V_w = 1$ ft per sec) = 576 Btuh per sq ft (F)

Similarly

f_w (at $V_w = 2$ ft per sec) = 1002 Btuh per sq ft (F)

Assuming $A_w = 1$ and substituting the proper numerical values in Eq. 7, the total resistance to the transfer of heat from the water within the tube to the air surrounding the baseboard when the water velocity is 1 ft per sec is found to be:

$$R_1 = \frac{1}{1 \times 576} + \frac{1}{20 \times 2} = 0.00174 + 0.025 = 0.02674 \qquad (9)$$

or the over-all coefficient of heat transfer is

$$U_1 = 1/R_1 = 1/0.02674 = 37.4 \text{ Btuh per sq ft (F)} \qquad (10)$$

In like manner at a water velocity of 2 ft per sec

$$R_2 = 0.02599$$

$$U_2 = 38.45 \text{ Btuh per sq ft (F)}$$

For any given water to air temperature difference the heat transfer rate is directly proportional to the

values of the heat transfer coefficient and since

$$H = CW^x \qquad (11)$$

then

$$\frac{H_2}{H_1} = \left(\frac{W_2}{W_1}\right)^x \text{ or } 38.45/37.4 = (2/1)^x = 1.028 \qquad (12)$$

$$x = 0.0399$$

as compared to the average experimental value of $x = 0.0402$.

The values selected in the preceding example are representative of current practice. It can be shown that changes in physical dimensions and operating conditions likely to be encountered with baseboard will not greatly affect the value of "x." For example, changing the ratio of A_o/A_w from 20 to 25 changes "x" from 0.04 to 0.05 (assuming the fin temperature to be the same over the entire fin area in each case). Changing the tube diameter from ¾ in. to 2 in. changes "x" from 0.040 to 0.047. Changing f_1 from 2 (air velocity approximately 200 ft per min) to 3 (air velocity approximately 600 ft per min) has the greatest effect on "x," changing its value from 0.040 to 0.057.

It is very difficult to determine the value of "x" experimentally with any high degree of accuracy. For example, assuming a baseboard with a heat output rate of 1000 Btuh per linear ft at a water flow rate of 500 lb per hr, if the value of "x" for this unit was 0.04, the heat output at a water flow rate of 1500 lb per hr would be 1045 Btuh per linear ft. If the value of "x" was 0.05, the heat output rate at a water flow rate of 1500 lb per hr would be 1056 Btuh per linear ft. Thus, an error in the measurement of the heat output of only 11 Btuh per linear ft would be sufficient to change the slope from 0.04 to 0.05. Therefore, to establish the value of "x" for the unit in this example to an accuracy of ±0.01 with a 10 ft unit it would be necessary to measure the temperature drop through the test unit with an accuracy of $\frac{10 \times 11}{1500} = 0.073$ F. Measuring the temperature drop to this accuracy requires a more accurate temperature measuring technique than can be expected from most commercial laboratories.

Substituting the exponent 0.04 in place of "x" in Eq. 12 it becomes possible to test the unit at one flow rate and compute the heat output at the other flow rates. If the tests are run at a flow rate of 500 lb of water per hr the outputs at flow rates other than 500 lb per hr are obtained by multiplying the test output by the appropriate factor in Table 7.

Since the exponent 0.04 does not apply to all units exactly, the use of the factors in Table 7 will result in some difference in computed output as compared to the true outputs. The magnitude of this error is indicated in Fig. 15. The maximum flow

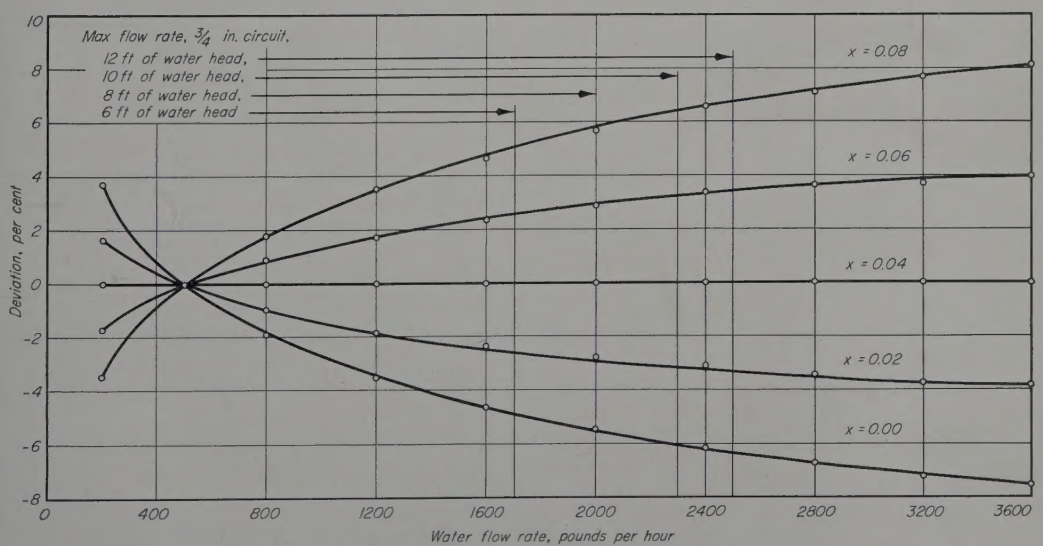

Fig. 15. Percent Deviation in Correction for Various Values of "x" Compared to "x" = 0.04

rates which may occur in hot water systems having equivalent circuit lengths of about 150 ft, designed in accordance with I = B = R Installation Guides 100 and 5, are also indicated in this figure. At a maximum flow rate of 2500 lb per hr, the difference between the "true" output of the unit and that computed using the factors in Table 2 was 3.0% or less in 19 of the 32 units listed in Table 6, between 3.0 and 5.0% in 7 cases and greater than 5.0% in 6 cases. The maximum error for any unit at a flow rate of 2500 lb per hr was 6.7%.

It is recommended that laboratory tests for baseboard rating purposes be made using a standard test water flow rate of 500 lb per hr and that ratings for other flow rates be obtained by applying the correction factors listed in Table 7. This recommendation is based on the following facts:

1. The inability to accurately determine the value of the exponent "x" by experimental means.
2. The excessive time and expense required to run the tests needed to determine the value of "x" by experimental means.
3. The relatively small error which may be introduced by using the factors listed in Table 7 as compared to "true" values.
4. Analytical analysis indicated that the value of "x" is relatively independent of the design of the heating unit.
5. The average value of "x" as determined by 32 series of tests and 16 different baseboard units and as determined by analytical means was approximately 0.04. This value was used in developing Table 7.